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SSS-A SPACECRAFT MAGNETIC TESTS

T. N. ROY

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SSS-A SPACECRAFT

MAGNETIC TESTS

T. N. Roy
Test and Evaluation Division
Systems Reliability Directorate

October 1971

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

SSS-A SPACECRAFT

MAGNETIC TESTS

Test Engineers: W. D. Kenney, T. N. Roy, J. C. Boyle, C. A. Harris
Magnetic Test Engineers

Prepared By: Thomas N. Roy
T. N. Roy
Magnetic Test Section

Reviewed By: C. Leland Parsons
C. Leland Parsons
Head, Magnetic Test Section

Approved By: Fred Starbuck
Fred Starbuck
Associate Chief,
Test and Evaluation Division

PROJECT STATUS

This is the final report of magnetic tests completed on the SSS-A spacecraft. SSS-A was successfully launched November 15, 1971 from the San Marco launch platform and is now designated Explorer 45.

AUTHORIZATION

Test and Evaluation Charge No. 325-857-11-25-02

SSS-A SPACECRAFT MAGNETIC TESTS

T. N. Roy
Test and Evaluation Division

SUMMARY

The SSS-A spacecraft was tested in the GSFC Sapcecraft Magnetic Test Facility (SMTF). The initial magnetic tests took place February 23-26, 1971, and the final tests, September 7-8, 1971.

In the initial magnetic tests the spacecraft perm moment as received was 43 milliampere-meter squared (pole-cm), which was reduced by deperm treatment to 34 mA-m^2. Facility fluxgate probe bias results indicated Z axis bias at the SSS-A fluxgate magnetometer position to be about one half nanotesla (gamma) after Z axis deperm. The ASCS magnetometers, 01 and 02, were successfully aligned and proper operation of the ASCS system were verified. The spacecraft fluxgate magnetometer was calibrated in both the high and low sensitivity modes after a defective 01 electronics card was replaced. Problems were encountered in the Z axis search coil during calibration and the test was re-scheduled.

Final test results indicate that the total perm moment could not be reduced any lower than about 35 mA-m^2 by deperm treatment. However, the Z axis moment decreased from 22 mA-m^2 to 6 mA-m^2 after deperm. Correct operation and calibration was verified for all three axes of the spacecraft fluxgate magnetometer and no significant bias was observed during stray field testing. Null and spot calibration of the ASCS magnetometer was completed and the measured spin and attitude coil moments were:

Spin Moment = 2535 mA-m^2

Attitude Moment = 9820 mA-m^2

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SSS-A SPACECRAFT
MAGNETIC TESTS

INTRODUCTION

The Small Scientific Satellite (SSS-A) is a spin stabilized spacecraft designed to study particles and fields in the inner magnetosphere. It is spin stabilized at a nominal rate of 4 RPM and is to be placed in an elliptical equatorial orbit with a low perigee and an apogee altitude of about four earth radii.

Spin stabilization is produced by an interaction torque between the magnetic moment generated perpendicular to the spin axis by an onboard toroidal "air-core" coil and the earth's ambient magnetic field. The attitude of the spacecraft is controlled by a separate "air-core" coil producing a magnetic moment along the spin axis.

Corrections to spin and attitude are made during perigee passes. When the ambient magnetic field increases to a certain threshold level as sensed by the ASCS magnetometer, the coil current is commanded on and when the ambient field falls below this level the coil current is triggered off.

Three magnetometers are located on the SSS-A. A single axis probe aligned with the X axis of the spacecraft is used to control the ASCS system. The second magnetometer, a three-axis fluxgate, is located 1.1 meter above the center of the satellite along the spin axis. This magnetometer with high and low sensitivities, is used to measure steady or slowly varying magnetic fields. Magnetometer number three is an A.C. search coil instrument. The Z probe is located on a boom along the +Y spacecraft axis and the X-Y probe is located in the -Y direction. (Fig. 1)

TEST OBJECTIVES

1. Measure initial permanent dipole moment of spacecraft and initial permanent field bias at fluxgate magnetometer.

2. Measure permanent dipole moment and field bias at fluxgate magnetometer after 15 gauss exposure.

3. Measure dipole moment and field bias at fluxgate magnetometer after deperm.

4. Determine dipole moment and field bias at fluxgate magnetometer due to solar simulation.

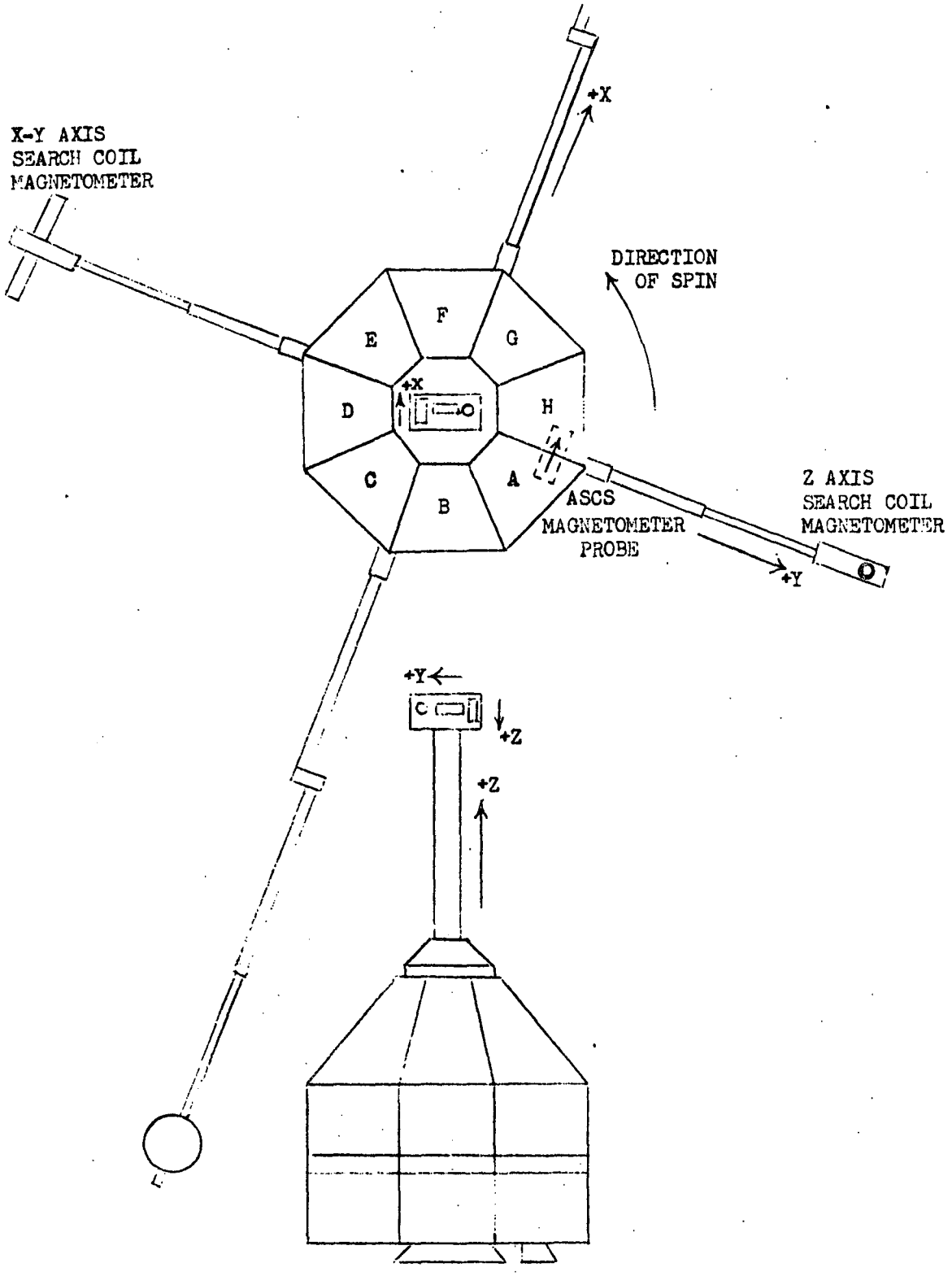

Figure 1. SSS-A Magnetometer Locations

5. Measure stray dipole moments and field bias at fluxgate magnetometer due to operation of spacecraft subsystems and experiments. Determine effect of ASCS coil operation on subsystems and experiments.

6. Align and calibrate fluxgate experiment sensors.

7. Verify function of search coil magnetometer.

8. Align, calibrate and check null of ASCS magnetometer probe.

9. Verify proper static and dynamic torquing capabilities of spin and attitude control coils.

TEST DESCRIPTION

Apparatus - Magnetic tests were conducted in the GSFC Spacecraft Magnetic Test Facility (SMTF). This facility which is described in Appendix A, utilizes a 13 meter diameter three axis coil system to produce a controlled magnetic environment of high uniformity over a large central volume.

SSS-A was mounted on the Mark VI Torquemeter, which was bolted to the turntable dolly, and then rolled into the coil system. Magnetic measurements were made at four locations, shown in Figure 2 and Figure 2A, using Forster Hoover Model MF 5050 triaxial probes. The signals from the probes were hard-wired to the Operations and Instrumentation Building for monitoring as analog traces on two eight-channel brush recorders and digitized on magnetic tape. Spacecraft orientation for magnetic measurements was:

Spacecraft Axes	+X . . .	South
	+Y . . .	West (Figure 3)
	+Z . . .	Up

For fluxgate magnetometer measurements the spacecraft was rotated 157° counterclockwise and the resulting magnetometer alignment was:

Spacecraft	+X . . .	North
Magnetometer Axes	+Y . . .	West (Fig 4)
	+Z . . .	Down

In the initial magnetic tests fluxgate probe bias was measured using a SMTF fluxgate probe positioned in the same space normally occupied by the spacecraft

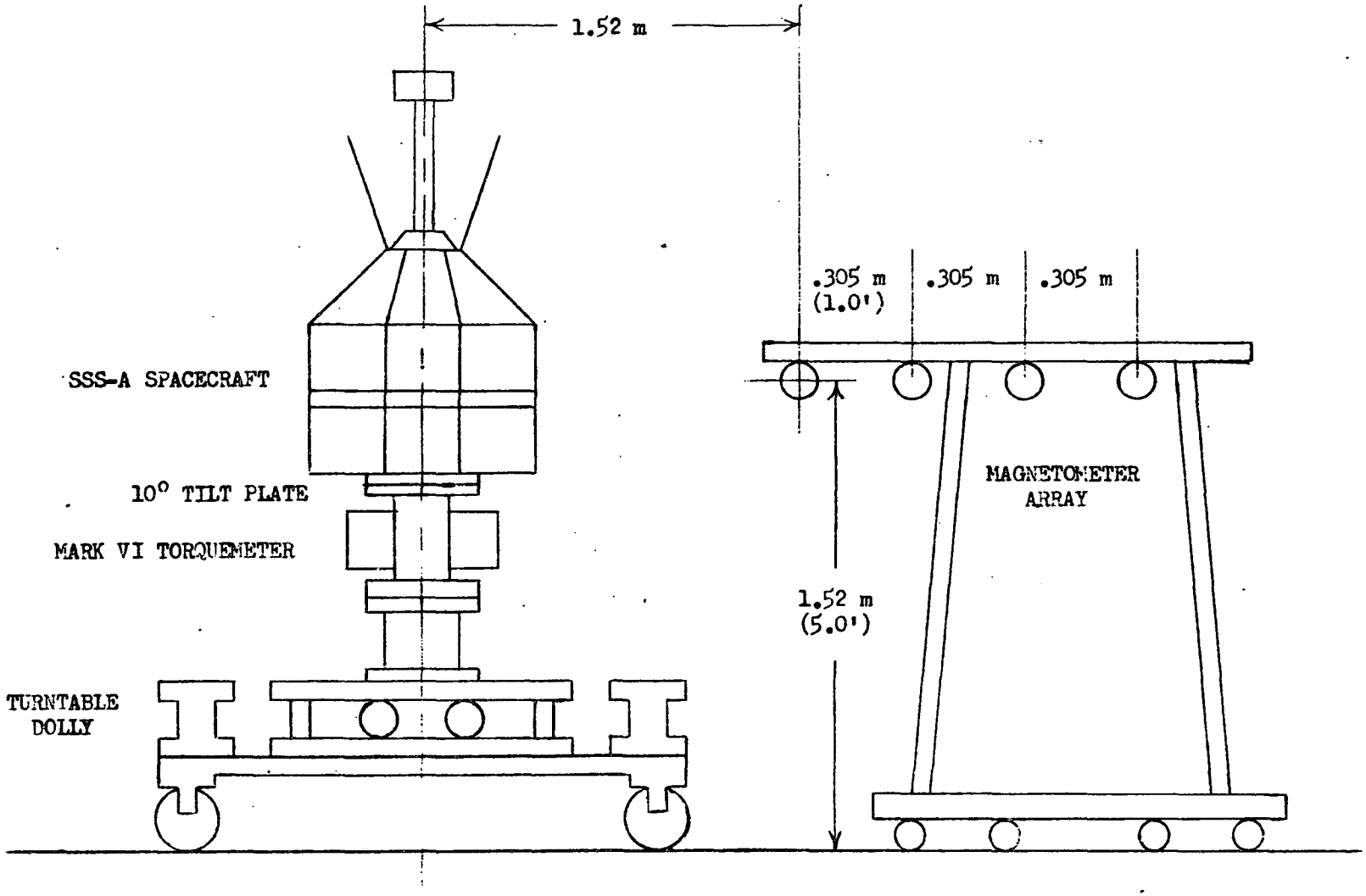

Figure 2. SSS-A Final Magnetic Test Set-Up

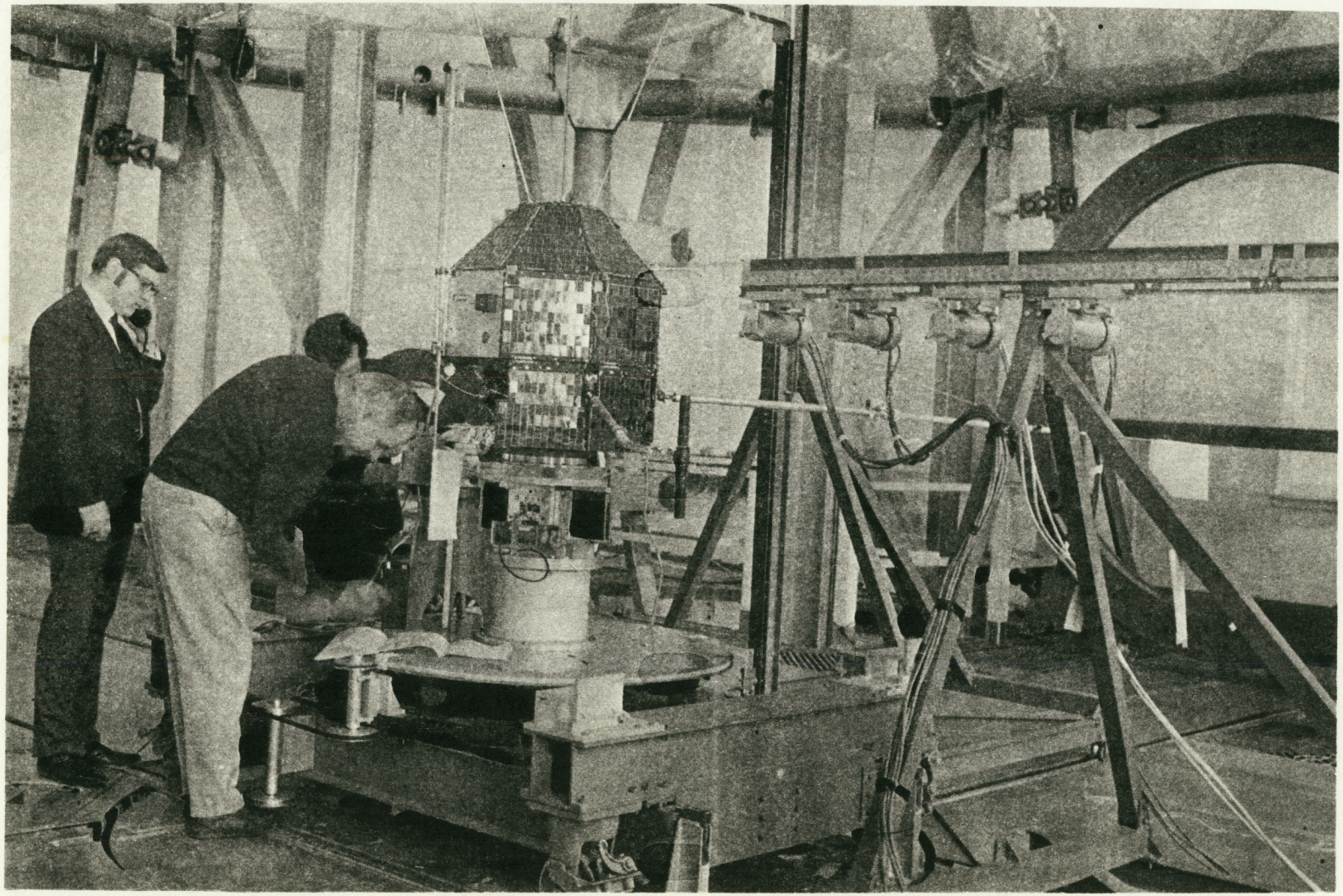

Figure 2A. SSS-A Final Magnetic Test Set-Up

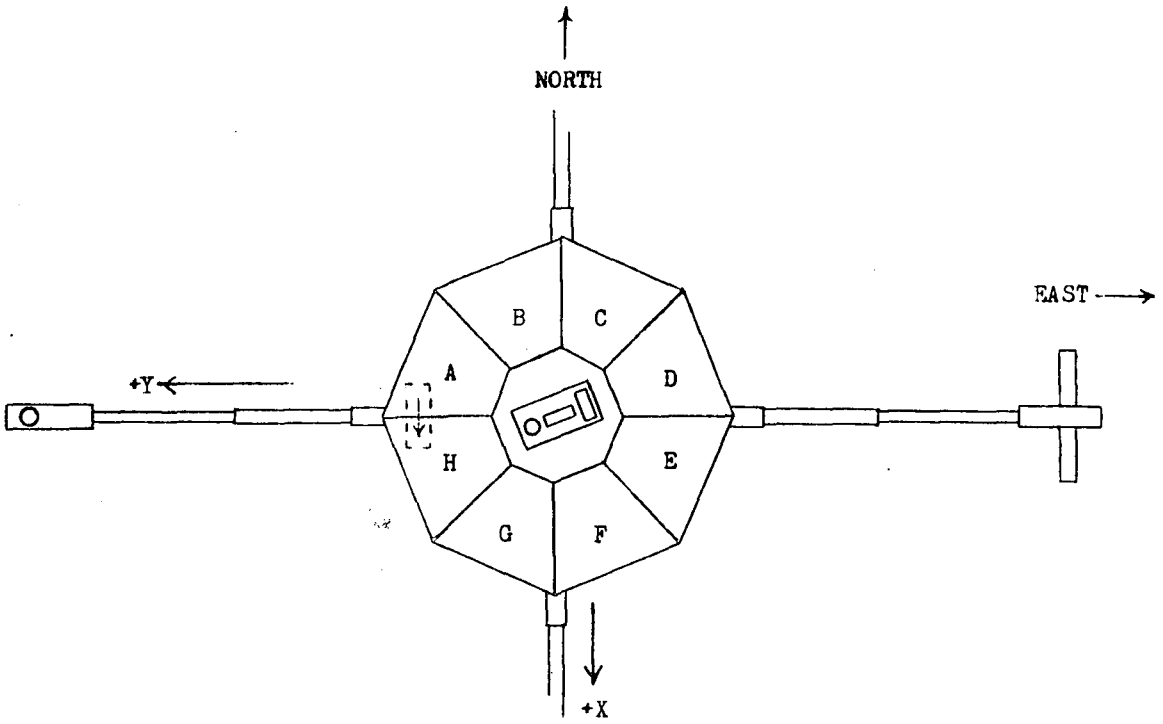

Figure 3. Orientation for Initial Magnetic Tests and All ASCS System Tests

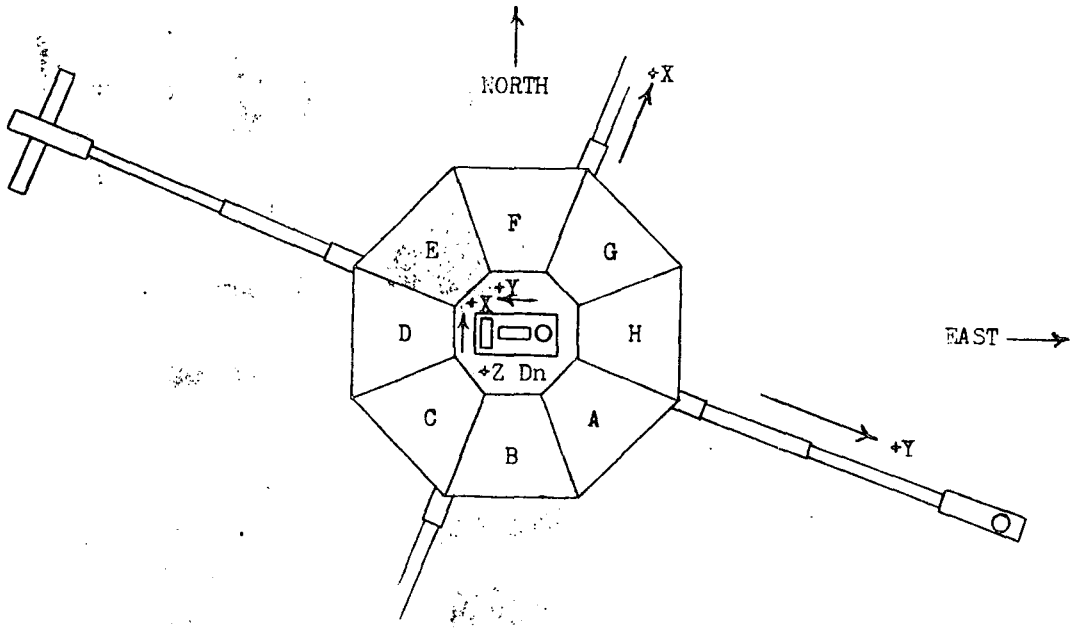

Figure 4. Orientation for Spacecraft Fluxgate Magnetometer Tests and Final Magnetic Tests

probe but with different sensor axes:

SMTF	X . . .	East
Magnetometer Axes	Y . . .	South
	Z . . .	Down

Magnetometer bias was checked with the actual flight magnetometer in the final tests.

Fluxgate magnetometer calibration was done with the spacecraft in the center of the SMTF coil, using calibrated magnetic field steps applied along each fluxgate sensor axis. The A.C. search coil calibration was done in Building 307, (Quiet Lab #2) where A.C. field interference could be reduced to a mimimum.

Horizontal axis exposure and deperm were accomplsihed using two 2.75 meter diameter coils moved to the center of the coil system on tracks. For Z axis exposure and deperm treatment a 1.5 meter diameter Helmholtz coil was lowered over the spacecraft.

Two calibrated air-core coils were mounted on the torquemeter with their axes oriented along the North-South and East-West axes of the coil system. The air-core coils were used to calibrate the torquemeter and for spacecraft magnetic moment measurements, producing magnetic moments equal and opposite to the spacecraft moments. During torquemeter evaluation of the ASCS system the spin axis of the SSS-A was vertical, however, during attitude control tests the spin axis was tilted 10° west to produce a horizontal component along the torquemeter measurement axis. The spacecraft center of mass was kept reasonably close to its original position with a 98.2 newton counterweight. Data obtained during torquemeter measurements were recorded on two 2-channel Sanborn recorders.

Procedure

1. Determine initial permanent magnetic moment of the spacecraft (initial and final tests).

2. Measure fluxgate magnetometer bias.
   a. Initial test - facility fluxgate.
   b. Final test - spacecraft fluxgate.

3. Determine moment after magnetic exposure.
   a. Initial test - 15×10^{-4} tesla (15 gauss), all three axes.
   b. Final test - 3×10^{-4} tesla, Z axis only.

4. Determine magnetic moment after deperm treatment.
   a. Initial test - 25×10^{-4} tesla, all three axes.
   b. Final test - 10×10^{-4} tesla, Z axis only.

5. Measure spurious moments and fluxgate magnetometer bias due to operation of spacecraft subsystems and experiments.
   a. Initial test - facility fluxgate.
   b. Final test - spacecraft fluxgate.

6. Calibrate search coil magnetometer (initial test).

7. Align and calibrate fluxgate magnetometer.
   a. Initial test - calibration.
   b. Final test - spot calibration.

8. Align and calibrate ASCS magnetometer sensor.
   a. Initial test - calibration.
   b. Final test - spot calibration.

9. Verify proper static and dynamic torquing capabilities of spin and attitude control coils.
   a. Magnetometer measurement.
   b. Torquemeter measurement.

RESULTS AND DISCUSSION

Initial Test

Magnetic Moments - Table I lists the magnetic moment history of the SSS-A during initial perm, exposure, deperm, and post stray measurements. Spacecraft orientation during these tests was +X . . . South, +Y . . . West, and +Z . . . Up. (See Figure 3)

Fluxgate Magnetometer Bias - Table II lists the magnetic bias measured at the spacecraft magnetometer position using a facility fluxgate probe. Z axis bias was reduced to less than the nominal value of one nanotesla (gamma) as requested.

Tests were run during the Y axis exposure and deperm measurements with the EFE antenna booms folded up and then down (flight position) to determine what effect their position had on the probe bias. Except for these two measurements the rest of the data were taken with the booms in the flight position.

Table I

Magnetic Moments - Initial Tests

Magnetic State	Magnetic Moment ($mA-m^2$)			
	M_x	M_y	M_z	M_t
Initial Perm	+ 17	- 24	- 31	43
Post -Y Exposure	+ 44	-242	- 30	248
Post Y Deperm	+ 9	- 2	- 23	25
Post -X Exposure	-182	- 46	- 25	189
Post X Deperm	+ 26	- 15	- 19	36
Post -Z Exposure	+ 26	- 26	-229	232
Post Z Deperm	+ 22	- 20	+ 34	45
Post Stray	+ 28	- 20	+ 25	43
Post 60 Hz Deperm	+ 23	- 19	- 16	34

Stray modes listed in Table II are defined as follows:

1(a) DPS in data mode; all instrumentation and experiments on except ASCS, SCADS and EXMTR. External Power.

2(a) Same as 1(a) but SCADS on.

2(b) Same as 1(a) but EXMTR on.

2(c) Same as 2(b) but internal power.

3 DPS in acc. subcom. mode; all instrumentation and experiments on except ASCS and SCADS. External power.

4 Same as 1(a) but ASCS electronics on (attitude and spin coils off).

5 Same as 4 but attitude coil on.

Probe bias measurements made during solar simulation using the spacecraft fluxgate magnetometer indicated negligible bias due to solar currents of about .45 ampere.

Table II

Facility Fluxgate Probe Bias Results

Magnetic State (Boom Position)	Probe Bias (Nanotesla)		
	X	Y	Z
Initial Perm	+ 1.40	+ 2.47	+ 1.73
Post -Y Exposure			
Booms Down	+11.93	+ 6.18	+ 3.96
Booms Up	+12.07	+ 6.00	+ 4.45
Post Y Deperm			
Booms Down	+ 0.67	+ 2.09	+ 1.41
Booms Up	+ 0.79	+ 2.12	+ 1.98
Post -X Exposure	+ 4.90	- 7.71	+ 2.52
Post X Deperm	+ 0.93	+ 3.15	+ 1.34
Post Z Exposure	+ 1.43	+ 1.88	>32.00
Post Z Deperm	+ 1.01	+ 2.84	- 2.25
Stray Modes			
1(a)	+ 0.64	+ 2.52	- 1.26
2(a)	+ 0.67	+ 2.52	- 0.99
2(b)	+ 0.57	+ 2.52	- 0.99
2(c)	+ 2.08	+ 6.14	+ 0.54
3	+ 0.57	+ 2.79	- 1.05
4	+ 0.62	+ 2.79	- 0.89
5	- 3.40	>32.00	>32.00
Post Stray	+ 1.02	+ 2.82	- 1.93
Post 60 Hz Z Deperm	+ 1.15	+ 2.64	+ 0.58

Search Coil Calibration - The spacecraft was moved to Quiet Lab #2 for A.C. search coil tests. All 60 Hz power was cut off and the measured residual 60 Hz magnetic noise was about one nanotesla. Problems were encountered in calibrating the Z axis search coil and it was decided that the problem be resolved at the University of Minnesota. The test was rescheduled for a later date to verify correct operation and calibration.

Fluxgate Magnetometer Calibration - The fluxgate magnetometer was calibrated in 10 nanotesla steps from -400 to +400 nanoteslas in the high sensitivity mode and from -400 to +400 nanoteslas in 100 nanotesla steps in the low sensitivity mode. During initial measurements it was found that the fluxgate 01 electronics card was not operating properly. The 01 electronics were replaced with an alternate system and the calibration was completed.

The zero crossing detector was also operated during these tests. A clockwise rotating field (3.75 RPM) was used to trigger the roll pulse. A zero crossover pulse was verified for perigee (10,000 nanoteslas), intermediate (1000 nanoteslas) and apogee (100 nanoteslas). Threshold for this detector was about 30 nanoteslas, below this value a double pulse was observed. Difficulty was experienced in determining the correct phase of the generated coil pulse and an additional test was scheduled to verify correct operation.

ASCS System Tests - ASCS magnetometers, 01 and 02, were successfully aligned and calibrated during this test. Null data were taken with zero field in the coil system, spin and attitude data was taken with the coils energized.

01 Unit	02 Unit
Null = +0.007 volt	Null = +0.001 volt
A+ = +0.011 volt	A+ = -0.006 volt
A- = +0.008 volt	A- = +0.020 volt
S+ = +0.003 volt	S+ = +0.002 volt
S- = +0.017 volt	S- = +0.002 volt

In the above data, the magnetometer alignment objective of two degrees corresponds to .045 volt for the attitude coil and .007 volt for the spin coil.

ASCS magnetometer calibration was done in steps from 0 to 60 microtesla (0.6 gauss) north, back down through zero to 60 microtesla south and back to zero again. Spacecraft orientation during calibration was spacecraft +Y axis west.

ASCS dynamics were verified by applying a 40 microtesla (0.4 gauss) field rotating at 4 RPM, spin +, spin -, attitude +, and attitude -, modes were checked using facility magnetometers to monitor the fields produced by the coils.

Attitude direct mode was checked, using a compass held near the top of the attitude coil with a 50 microtesla (.5 gauss) horizontal field and observing a compass change of 30 degrees when the coil was energized.

Static measurement of spin and attitude coil turn-on thresholds were (GSE data):

S+ Mode	A+ Mode
Coil on .715 volt	Coil on .734 volt
Coil off .673 volt	
Coil on .693 volt	
Coil off-.561 volt	

The nominal value for ASCS coil turn-on threshold is .750 volt.

Final Test

Magnetic Moment - Table III lists the magnetic moment history of the SSS-A during final magnetic tests. Spacecraft orientation was changed from the initial test with the SSS-A rotated 157 degrees counterclockwise. See Figure 4.

Table III

Magnetic Moments - Final Tests

Magnetic State	Magnetic Moment ($mA\text{-}m^2$)		
	M_{xy}	M_z	M_t
Initial Perm	24.9	-22.2	33.4
Post 10^{-3} Tesla 60 Hz Deperm Z Axis	35.3	+ 5.7	35.8

Fluxgate Magnetometer Bias - The initial perm field was also measured by the spacecraft fluxgate magnetometer and no significant bias was seen. Also, during stray field testing and post Z axis deperm, negligible bias was measured.

Fluxgate Magnetometer Calibration - Spot calibration check of fluxgate magnetometer verified correct operation and calibration on all three axes.

ASCS System Tests - For the final ASCS tests the spacecraft was rotated until the Z search coil magnetometer was west (Figure 3). Alignment was slightly better than one degree.

ASCS coil interaction:

Null = -.007 volt
S+ = -.002 volt
S- = -.007 volt
A+ = -.004 volt
A- = +.001 volt

Threshold values for spin and attitude coil activation:

7.0 Microtesla North - Spin Coil On
5.8 Microtesla North - Spin Coil Off

7.2 Microtesla South - Spin Coil On
6.9 Microtesla South - Spin Coil Off

7.5 Microtesla North - Attitude Coil On
5.0 Microtesla North - Attitude Coil Off

ASCS magnetometer calibration: a small bias was noticed during the ASCS calibration which seems to be directed north at fields of about 50 microtesla (.5 gauss) and may be due to permeable material near the ASCS magnetometer probe or its associated electronics.

CONCLUSIONS

The SSS-A was an exceptionally non-magnetic spacecraft having an initial perm moment of 43 mA-m^2 (pole-cm) which was reduced after final deperm treatment. The final perm magnetic moment was 35 mA-m^2 in the X-Y plane and 6 mA-m^2 along the vertical axis.

Z axis fluxgate magentometer bias was reduced to less than one nanotesla (gamma) as requested in the test procedure and the spacecraft magnetometer calibration confirmed correct operation on all three axes.

ASCS system tests verified the proper alignment and operation of the ASCS magnetometer probe. Attitude and spin coil thresholds were measured and the

Table IV

ASCS Magnetometer Calibration

Facility Field*	ASCS Magnetometer Output (Volts)	Facility Field*	ASCS Magnetometer Output (Volts)
5.0 N	- .506 V	5.0 S	+ .502 V
5.5	.559	7.5	.754
6.0	.622	10.0	1.005
8.0	.823	20.0	2.012
9.0	.924	30.0	3.012
10.0	1.023	40.0	4.006
20.0	2.023	50.0	4.989
30.0	3.030	60.0	5.946
40.0	4.036		
50.0	5.046		
60.0	6.063		

*Facility field in microteslas (10^{-2} gauss)

Torquemeter measurement of spin and attitude coil moments:

Table V

ASCS Torque Coil Moments

ASCS Mode	Moment ($mA-m^2$)	Direction*
Spin +	2534	East
Spin -	2534	West
Attitude +	9816	Down
Attitude -	9822	Up
Attitude Direct	9713	Down

*Facility magnetic field in north direction

ASCS electronics were shown to be functioning properly. Measured ASCS torque coil moments were:

Spin Moment = 2534 mA-m^2
Attitude Moment = 9820 mA-m^2

REFERENCES

1. Flatley, Thomas W., Magnetic Attitude and Spin Control of the Small Scientific Satellite SSS-A, NASA TN D-5572, February 1970.

2. Boyle, J. C., SSS-A ETU Attitude and Spin Control Subsystem Magnetic Test, GSFC report X-325-70-237, May 1970.

3. SSS-A Spacecraft Initial (Pre-Vibrational) Magnetic Test Procedure, prepared by Magnetic Test Section and the SSS Project Office, dated February 23, 1971.

4. SSS-A Spacecraft Final Magnetic Test Procedure, prepared by K. O. Sizemore, GSFC, dated August 31, 1971, Procedures: SSS-701-17.

APPENDIX A

DESCRIPTION OF FACILITY

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DESCRIPTION OF MAGNETIC TEST FACILITY

The Spacecraft Magnetic Test Facility at Goddard Space Flight Center produces a controlled magnetic environment for magnetic tests of spacecraft or spacecraft components. The 12.65 meter (41.5 foot) diameter three-axis coil system permits establishment of zero field, or of a field of any desired magnitude and direction with a maximum of 60,000 nanotesla (gamma) per component. Current-regulated power supplies provide stability of ±1 nanotesla (gamma) over a 24-hour period, and the coil geometry provides uniformity of field within 0.6 nanotesla (gamma) over a spherical volume of 2-meter (6.6 foot) diameter. Three earth-field magnetometers and associated control systems provide automatic compensation for the daily variation of the earth's field. Figure 5 illustrates the total magnetic field reconnaisance survey of the magnetic test site.

Besides generating static magnetic fields, the coil currents are programmable to produce a resultant vector that will rotate about any desired axis through the center of the coil system at a maximum rate of 100 radians per second. The magntiude of the rotating vector has a maximum limit of 60,000 nanotesla (gamma).

The facility also includes a 22,240 newton (5,000 pound) capacity overhead hoist, an 8896 newton (2,000) pound capacity hydroset for gentle handling of delicate spacecraft, a track system and dolly for transporting the spacecraft from the trucklock to the center of the coil system, and a turntable at the coil center powered to rotate the spacecraft through 360 degrees while it is centered in the coil. An angle encoder on the turntable permits synchronization of angular position and magnetic measurements. A gimbal is available that can rotate the spacecraft about a horizontal axis, (Figures 6 and 7).

A portable Helmholtz coil pair of 2.7 meter (9 foot) diameter generates field up to 50×10^{-4} tesla (50 gauss) for perming and deperming the spacecraft along one axis. Also available is a 1.5 meter (5 foot) diameter coil for applying such fields along a second axis of the smaller spacecraft.

A series of highly sensitive torquemeters are available, permitting direct measurement of torques resulting from the interaction between the magnetic moment of the spacecraft under test and the field produced by the coil system itself. The torquemeters are also used to measure directly torques produced by the attitude control systems on spacecraft.

The equipment also includes four triaxial fluxgate magnetometers that can be used simultaneously to provide meter display, strip chart records, and digital printout records. The positions of the magnetometer probes can be varied to suit the particular needs of the spacecraft or subsystem under test (Figure 8).

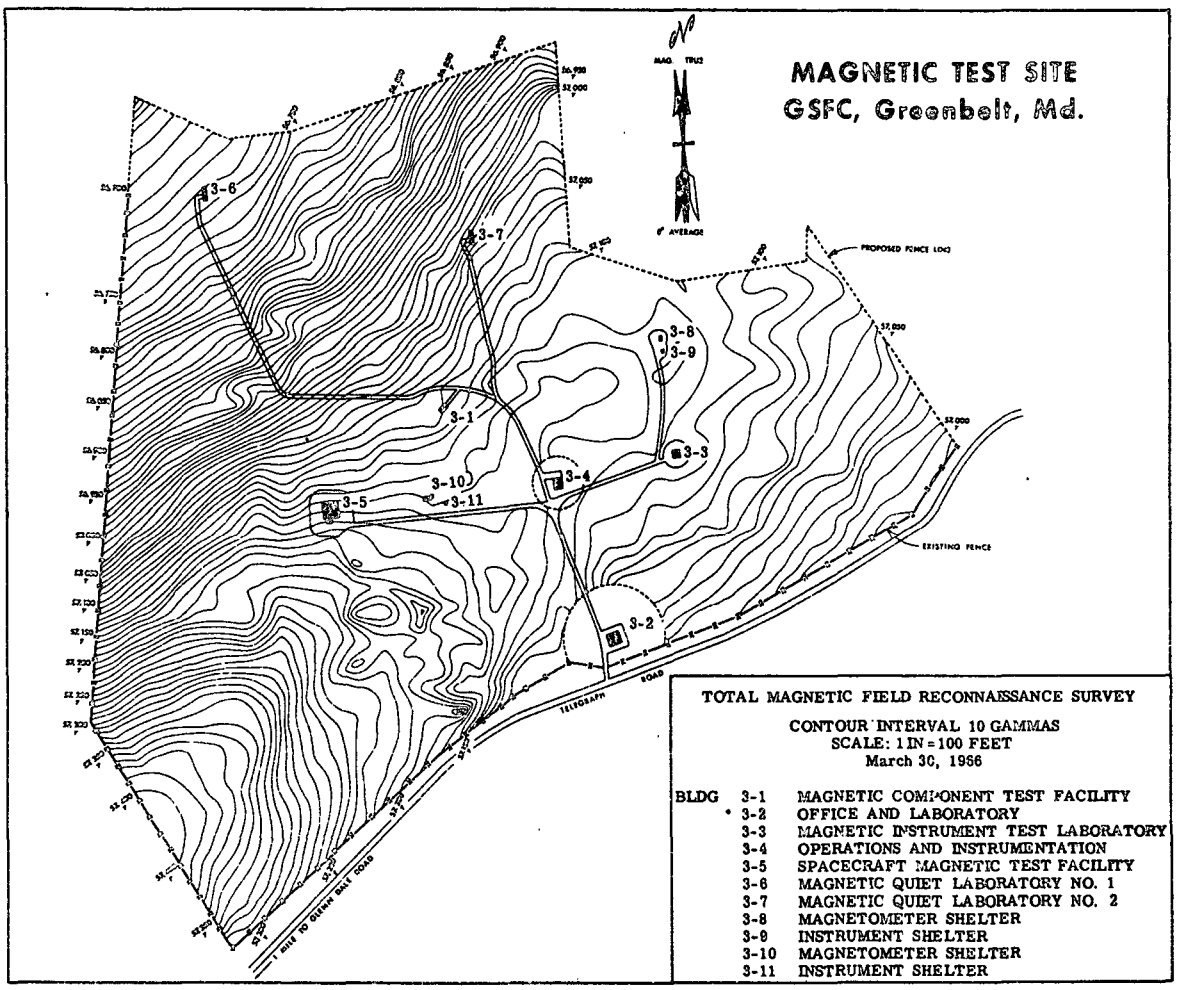

Figure 5. Total Magnetic Field Reconnaisance Survey of Magnetic Test Site

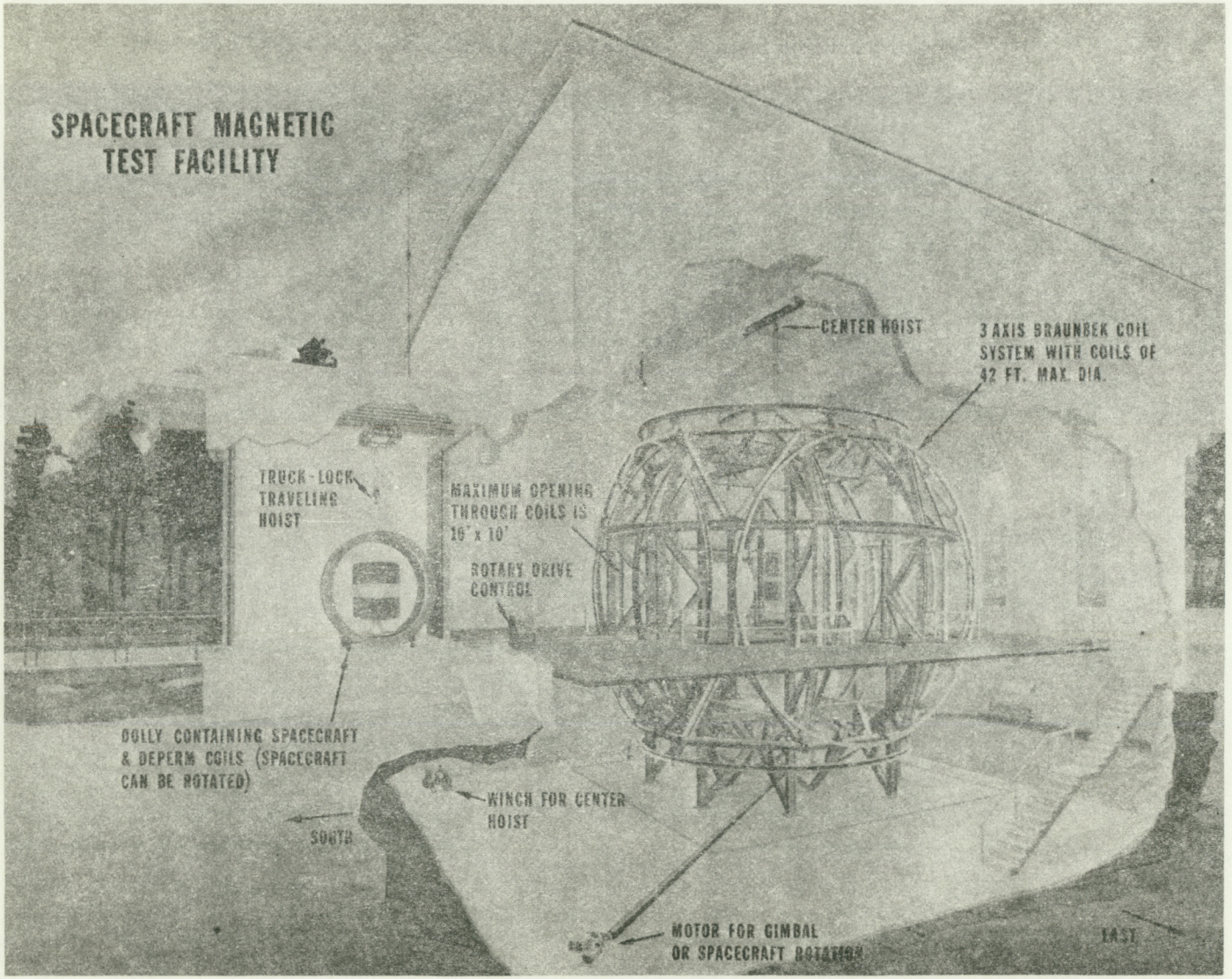

Figure 6. Spacecraft Magnetic Test Facility

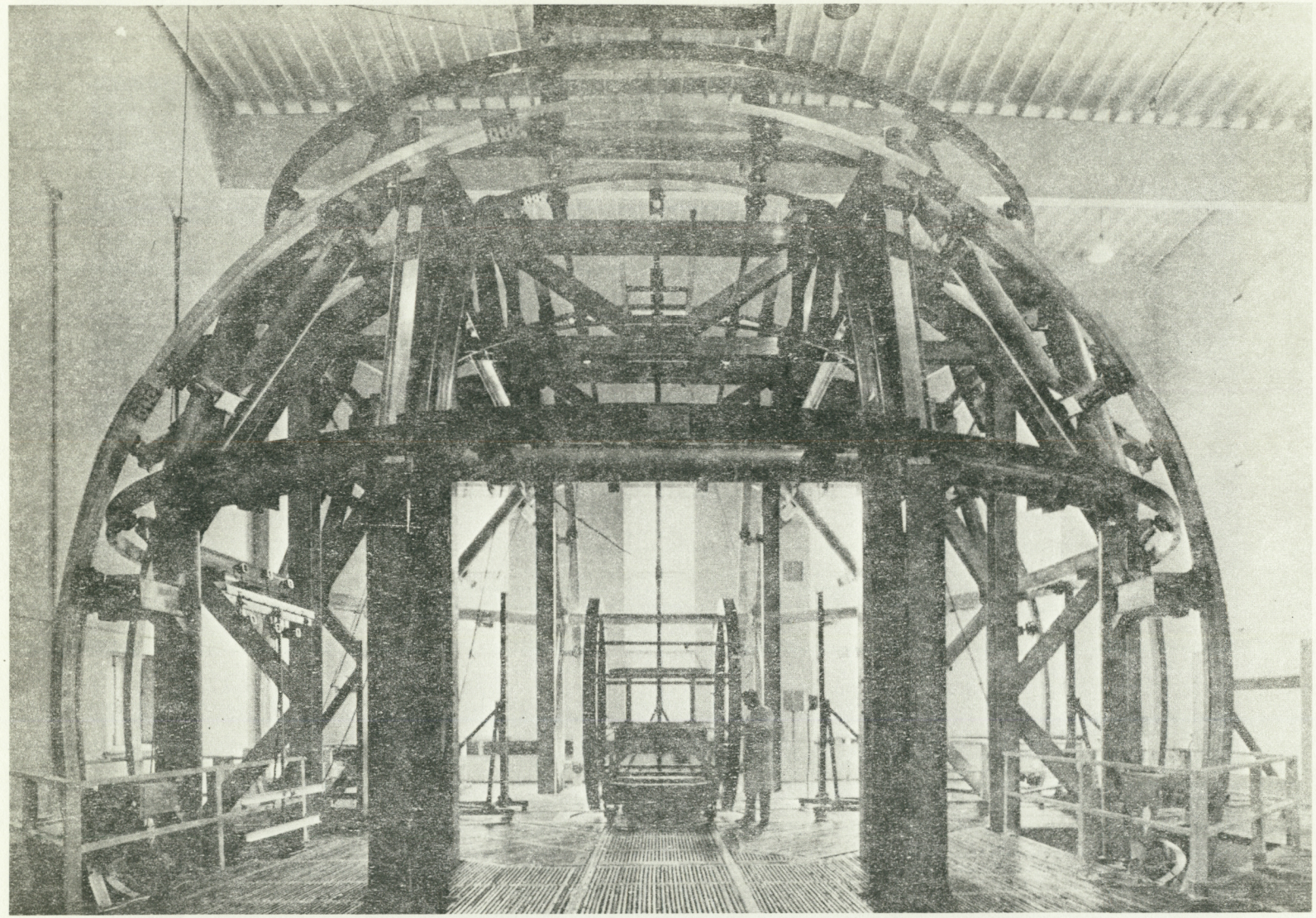

Figure 7. Spacecraft Magnetic Test Facility – 13 Meter Diameter 3-Axis Coil

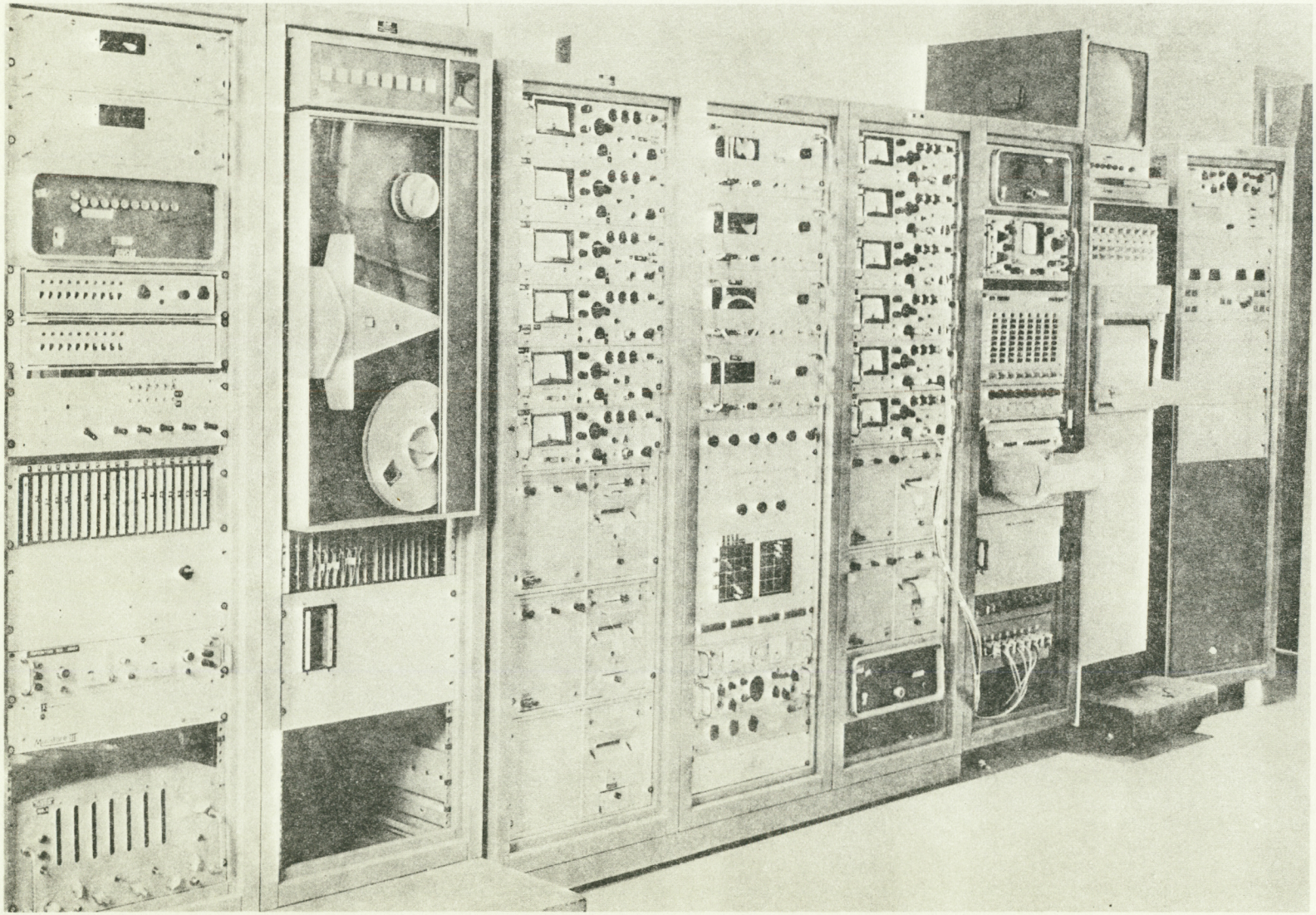

Figure 8. Recording Instrumentation for Magnetic Tests

APPENDIX B

CHRONOLOGY OF EVENTS

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CHRONOLOGY OF EVENTS

ETU Test	January 5-9, 1970
Preliminary	October 27 - November 2, 1970
Initial	February 23-26, 1971
Magnetic Check	May 25-26, 1971
Final Test	September 7-8, 1971

Tuesday, September 7, 1971:

The SSS-A was delivered to the Magnetic Test Site.

Initial magnetic measurements.

Exposure and deperm.

Stray Fields.

Fluxgate magnetometer check.

Wednesday, September 8, 1971:

ASCS system tests - torquemeter.

SSS-A departed Magnetic Test Site.